FERMENTATION

AND ITS BEARINGS ON

THE PHENOMENA OF DISEASE:

A DISCOURSE

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FERMENTATION.

In a book with which we are all familiar, amid other wise utterances, this one occurs: "Cast thy bread upon the waters; for thou shalt find it after many days." In more senses than one this precept is illustrated by my presence here to-night. Firstly, in a general sense, I stand indebted, morally and intellectually, to the poets, historians, and philosophers of Scotland. Secondly, in a special sense, it so happens that one of the first rootlets of my scientific life derived its nutriment from this city of Glasgow. In early youth it was my ambition to qualify myself for the profession of a civil engineer, and as I grew up one of my aids toward the attainment of this object was the study of a periodical then published in Glasgow, and called *The Practical Mechanic's and Engineer's Magazine.* In that journal I read, with an interest unfelt before, a series of essays on various departments of science—on anatomy and physiology, on geology, on mechanics, on arithmetic, and on natural philosophy and chemistry. Biography and history were also included, while in detached articles various collateral subjects were discussed, such, for example, as the difference between Newton and Leibnitz as to the measure of moving force. It was there that I first learned what Leslie had done in Edinburgh, and what Davy had done in the Royal Institution. And I can now call to mind the day and hour when the yearning to possess such apparatus as Leslie and Davy possessed, and to institute with it such inquiries as they had instituted, rose to a kind of prophetic strength within me—prophetic, for it

has come to pass that my own studies as a scientific man have been in great part pursued in that particular domain which had been enriched by the discoveries of Leslie; while the very instruments used by Davy, and which I first saw figured in the pages of the journal just mentioned, are the identical and familiar instruments with which my lectures in London are now illustrated.

Another point brought more or less home to me in those early days was the injury inflicted on the learner by bad scientific exposition. It does more than the negative damage of withholding instruction. It daunts the young mind, and saps the motive power of self-reliance. This I had experienced; and the essays referred to had this special value for me, that they not only instructed me, but gave me faith in my own capacity to be instructed. Since those days I have written books myself, and in doing so have tried to remember, and to act on the remembrance, that the labour spent in logically ordering one's thoughts, and in saying what one has to say clearly and correctly, is labour well bestowed.

The position assumed at the outset has, I think, been now made good. Glasgow in my case cast its bread upon the waters, and lo! it has returned after many days. Of the nutritive value of the return it is not for me to speak; for it may well have been soured by fortuitous ferments, mixed by the world's tainted atmosphere with the first pure leaven derived from the pages of *The Practical Mechanic's and Engineer's Magazine.*

The figure of speech here employed will become more intelligible as we proceed; for it is my desire and intention to spend the coming hour in speaking to you about *ferments,* not in a metaphorical, but in a real sense. Proper treatment is, I am persuaded, the only thing needed to make the subject both pleasant and profitable to you. For our knowledge of fermentation, and of the ground it covers, has augmented surprisingly of late, while every fresh accession to that knowledge strengthens the hope that its final issues will be of incalculable advantage to mankind.

One of the most remarkable characteristics of the age in

which we live, is its desire and tendency to connect itself organically with preceding ages—to ascertain how the state of things that now is came to be what it is. And the more earnestly and profoundly this problem is studied, the more clearly comes into view the vast and varied debt which the world of to-day owes to that fore-world, in which man by skill, valour, and well-directed strength first replenished and subdued the earth. Our pre-historic fathers may have been savages, but they were clever and observant ones. They founded agriculture by the discovery and development of seeds whose origin is now unknown. They tamed and harnessed their animal antagonists, and sent them down to us as ministers, instead of rivals in the fight for life. Later on, when the claims of luxury added themselves to those of necessity, we find the same spirit of invention at work. We have no historic account of the first brewer, but we glean from history that his art was practised, and its produce relished, more than two thousand years ago. Theophrastus, who was born nearly four hundred years before Christ, described beer as *the wine of barley*. It is extremely difficult to preserve beer in a hot country, still, Egypt was the land in which it was first brewed, the desire of man to quench his thirst with this exhilarating beverage overcoming all the obstacles which a hot climate threw in the way of its manufacture.

Our remote ancestors had also learned by experience that wine maketh glad the heart of man. Noah, we are informed, planted a vineyard, drank of the wine, and experienced the consequences. But, though wine and beer possess so old a history, a very few years ago no man knew the secret of their formation. Indeed, it might be said that until the present year no thorough and scientific account was ever given of the agencies which come into play in the manufacture of beer, of the conditions necessary to its health, and of the maladies and vicissitudes to which it is subject. Hitherto the art and practice of the brewer have resembled those of the physician, both being founded on empirical observation. By this is meant the observation of facts apart from the principles which explain them, and which give the mind an intelligent mastery over them. The brewer learnt from

long experience the conditions, not the reasons of success. But he had to contend, and he has still to contend, against unexplained perplexities. Over and over again his care has been rendered nugatory; his beer has fallen into acidity or rottenness, and disastrous losses have been sustained, of which he has been unable to assign the cause. It is the hidden enemies against which the physician and the brewer have hitherto contended, that recent researches are dragging into the light of day, thus preparing the way for their final extermination.

Let us glance for a moment at the outward and visible signs of fermentation. A few weeks ago I paid a visit to a private still in a Swiss chalet; and this is what I saw. In the peasant's bedroom was a cask with a very large bung-hole carefully closed. The cask contained cherries which had lain in it for fourteen days. It was not entirely filled with the fruit, an air-space being left above the cherries when they were put in. I had the bung removed, and a small lamp dipped into this space. Its flame was instantly extinguished. The oxygen of the air had entirely disappeared, its place being taken by carbonic acid gas.* I tasted the cherries : they were very sour, though when put into the cask they were sweet. The cherries and the liquid associated with them were then placed in a copper boiler, to which a copper head was closely fitted. From the head proceeded a copper-tube which passed straight through a vessel of cold water, and issued at the other side. Under the open end of the tube was placed a bottle to receive the spirit distilled. The flame of small wood splinters being applied to the boiler, after a time vapour rose into the head, passed through the tube, was condensed by the cold of the water, and fell in a liquid fillet into the bottle. On being tasted, it proved to be that fiery and intoxicating spirit known in commerce as Kirsch or Kirschwasser.

The cherries, it should be remembered, were here left to themselves, no ferment of any kind being added to them. In this respect what has been said of the cherry applies also

* The gas which is exhaled from the lungs after the oxygen of the air has done its duty in purifying the blood, the same also which effervesces from soda water and champagne.

to the grape. At the vintage the fruit of the vine is placed in proper vessels, and abandoned to its own action. It ferments, producing carbonic acid; its sweetness disappears, and at the end of a certain time the unintoxicating grape-juice is converted into intoxicating wine. Here, as in the case of the cherries, the fermentation is spontaneous—in what sense spontaneous will appear more clearly by-and-by.

It is needless for me to tell a Glasgow audience that the beer-brewer does not set to work in this way. In the first place the brewer deals not with the juice of fruits, but with the juice of barley. The barley having been steeped for a sufficient time in water, it is drained, and subjected to a temperature sufficient to cause the moist grain to germinate, after which it is completely dried upon a kiln. It then receives the name of malt. The malt is crisp to the teeth, and decidedly sweeter to the taste than the original barley. It is ground, mashed up in warm water, then boiled with hops until all the soluble portions have been extracted, the infusion thus produced being called the *wort*. This is drawn off, and cooled as rapidly as possible; then, instead of abandoning the infusion, as the wine-maker does, to its own action, the brewer mixes yeast with his wort, and places it in vessels, each with only one aperture open to the air. Soon after the addition of the yeast, a brownish froth, which is really new yeast, issues from the aperture, and falls like a cataract into troughs prepared to receive it. This frothing and foaming of the wort is a proof that the fermentation is active.

Whence comes the yeast which issues so copiously from the fermenting tub? What is this yeast, and how did the brewer become in the first instance possessed of it? Examine its quantity before and after fermentation. The brewer introduces, say 10 cwts. of yeast; he collects 40, or it may be 50 cwts. The yeast has, therefore, augmented from four to five fold during the fermentation. Shall we conclude that this additional yeast has been spontaneously generated by the wort? Are we not rather reminded of that seed which fell into good ground, and brought forth fruit, some thirty-fold, some sixty-fold, some an hundred-fold? On examination this notion of organic growth turns out to be more than

a mere surmise. In the year 1680, when the microscope was still in its infancy, Leeuwenhoek turned the instrument upon this substance, and found it composed of minute globules suspended in a liquid. Thus knowledge rested until 1835, when Cagniard de la Tour in France, and Schwann in Germany, independently, but animated by a common thought, turned microscopes of improved definition and heightened powers upon yeast, and found it budding and sprouting before their eyes. The augmentation of the yeast alluded to above was thus proved to arise from the growth of a minute plant, now called *Torula* (or *Saccharomyces*) *Cerevisiæ*. Spontaneous generation is therefore out of the question. The brewer deliberately sows the yeast-plant, which grows and multiplies in the wort as its proper soil. This discovery marks an epoch in the history of fermentation.

But where did the brewer find his yeast? The reply to this question is similar to that which must be given if it were asked where the brewer found his barley. He has received the seeds of both of them from preceding generations. Could we connect without solution of continuity the present with the past, we should probably be able to trace back the yeast employed by my friend Sir Fowell Buxton to-day, to that employed by some Egyptian brewer two thousand years ago. But you may urge that there must have been a time when the first yeast cell was generated. Granted—exactly as there was a time when the first barley-corn was generated. Let not the delusion lay hold of you, that a living thing is easily generated, because it is small. Both the yeast-plant and the barley-plant lose themselves in the dim twilight of antiquity, and in this our day there is no more proof of the spontaneous generation of the one, than there is of the spontaneous generation of the other.

I stated a moment ago that the fermentation of grape-juice was spontaneous; but I was careful to add, "in what sense spontaneous will appear more clearly by-and-by." Now this is the sense meant. The wine-maker does not, like the brewer and distiller, deliberately introduce either yeast, or any equivalent of yeast, into his vats; he does not consciously sow in them any plant, or the germ of any plant; indeed, he has been hitherto in ignorance whether plants or

germs of any kind have had anything to do with his operations. Still, when the fermented grape-juice is examined, the living *Torula* concerned in alcoholic fermentation never fails to make its appearance. How is this? If no living germ has been introduced into the wine vat, whence comes the life so invariably developed there?

You may be disposed to reply with Turpin and others, that in virtue of its own inherent powers, the grape-juice, when brought into contact with the vivifying atmospheric oxygen, runs spontaneously and of its own accord into these low forms of life. I have not the slightest objection to this explanation, provided proper evidence can be adduced in support of it. But the evidence adduced in its favour, as far as I am acquainted with it, snaps asunder under the least strain of scientific criticism. It is, as far as I can see, the evidence of men, who, however keen and clever as *observers*, are not rigidly trained *experimenters*. These alone are aware of the precautions necessary in investigations of this delicate kind. In reference, then, to the life of the wine vat, what is the decision of experiment when carried out by competent men? Let a quantity of the clear, filtered "must" of the grape be so boiled as to destroy such germs as it may have contracted from the air or otherwise. In contact with germless air the uncontaminated must never ferments. All the materials for spontaneous generation are there, but so long as there is no seed sown there is no life developed, and no sign of that fermentation which is the concomitant of life. Nor need you resort to a boiled liquid. The grape is sealed by its own skin against contamination from without. By an ingenious device Pasteur has extracted from the interior of the grape its pure juice, and proved that in contact with pure air it never acquires the power to ferment itself, nor to produce fermentation in other liquids.* It is not, therefore, in the interior of the grape that the origin of the life observed in the vat is to be sought.

* The liquids of the healthy animal body are also sealed from external contamination. Pure blood, for example, drawn with due precautions from the veins, will never ferment or putrefy in contact with pure air.

What then is its true origin? This is Pasteur's answer, which his well-proved accuracy renders worthy of all confidence. At the time of the vintage microscopic particles are observed adherent, both to the outer surface of the grape and of the twigs which support the grape. Brush these particles into a capsule of pure water. It is rendered turbid by the dust. Examined by a microscope some of these minute particles are seen to present the appearance of organised cells. Instead of receiving them in water, let them be brushed into the pure inert juice of the grape. Forty-eight hours after this is done, our familiar *Torula* is observed budding and sprouting, the growth of the plant being accompanied by all the other signs of active fermentation. What is the inference to be drawn from this experiment? Obviously that the particles adherent to the external surface of the grape include the germs of that life which, after they have been sown in the juice, appears in such profusion. Wine is sometimes objected to on the ground that fermentation is "artificial;" but we notice here the responsibility of nature. The ferment of the grape clings like a parasite to the surface of the grape, and the art of the wine-maker from time immemorial has consisted in bringing—and it may be added, ignorantly bringing—two things thus closely associated by nature into actual contact with each other. For thousands of years, what has been done consciously by the brewer, has been done unconsciously by the wine-grower. The one has sown his leaven just as much as the other.

Nor is it necessary to impregnate the beer-wort with yeast to provoke fermentation. Abandoned to the contact of our common air, it sooner or later ferments; but the chances are that the produce of that fermentation, instead of being agreeable, would be disgusting to the taste. By a rare accident we might get the true alcoholic fermentation, but the odds against obtaining it would be enormous. Pure air acting upon a lifeless liquid will never provoke fermentation; but our ordinary air is tho vehicle of numberless germs which act as ferments when they fall into appropriate infusions. Some of them produce acidity, some putrefaction. The germs of our yeast-plant are also in the air; but so sparingly

distributed that an infusion like beer-wort, exposed to the air, is almost sure to be taken possession of by foreign organisms. In fact the maladies of beer are wholly due to the admixture of these objectionable ferments, whose forms and modes of nutrition differ materially from those of the true leaven.

Working in an atmosphere charged with the germs of these organisms, you can understand how easy it is to fall into error in studying the action of any one of them. Indeed it is only the most accomplished experimenter, who, moreover, avails himself of every means of checking his conclusions, that can walk without tripping through this land of pitfalls. Such a man is the French chemist Pasteur. He has taught us how to separate the commingled ferments of our air, and to study their pure individual action. Guided by him, let us fix our attention more particularly upon the growth and action of the true yeast-plant under different conditions. Let it be sown in a fermentable liquid, which is supplied with plenty of pure air. The plant will flourish in the aërated infusion, and produce large quantities of carbonic acid gas—a compound, as you know, of carbon and oxygen. The oxygen thus consumed by the plant is the free oxygen of the air, which we suppose to be abundantly supplied to the liquid. The action is so far similar to the respiration of animals, which inspire oxygen and expire carbonic acid. If we examine the liquid even when the vigour of the plant has reached its maximum, we hardly find in it a trace of alcohol. The yeast has grown and flourished, but it has almost ceased to act as a ferment. And could every individual yeast cell seize, without any impediment, free oxygen from the surrounding liquid, it is certain that it would cease to act as a ferment altogether.

What, then, are the conditions under which the yeast-plant must be placed so that it may display its characteristic quality? Reflection on the facts already referred to suggests a reply, and rigid experiment confirms the suggestion. Consider the Alpine cherries in their closed vessel. Consider the beer in its barrel, with a single small aperture open to the air, through which it is observed not to imbibo oxygen, but to pour forth carbonic acid. Whence come the volumes

of oxygen necessary to the production of this latter gas? The small quantity of atmospheric air dissolved in the wort and overlying it would be totally incompetent to supply the necessary oxygen. In no other way can the yeast-plant obtain the gas necessary for its respiration than by wrenching it from surrounding substances in which the oxygen exists, not free, but in a state of combination. It decomposes the sugar of the solution in which it grows, produces heat, breathes forth carbonic acid gas, and one of the liquid products of the decomposition is our familiar alcohol. The act of fermentation, then, is a result of the effort of the little plant to maintain its respiration by means of combined oxygen, when its supply of free oxygen is cut off. As defined by Pasteur, fermentation is *life without air*.

But here the knowledge of that thorough investigator comes to our aid to warn us against errors which have been committed over and over again. It is not all yeast cells that can thus live without air and provoke fermentation. They must be young cells which have caught their vegetative vigour from contact with free oxygen. But once possessed of this vigour the yeast may be transplanted into a saccharine infusion absolutely purged of air, where it will continue to live at the expense of the oxygen, carbon, and other constituents of the infusion. Under these new conditions its life *as a plant* will be by no means so vigorous as when it had a supply of free oxygen, but its action *as a ferment* will be indefinitely greater.

Does the yeast-plant stand alone in its power of provoking alcoholic fermentation? It would be singular if amid the multitude of low vegetable forms no other could be found capable of acting in a similar way. And here again we have occasion to marvel at that sagacity of observation among the ancients to which we owe so vast a debt. Not only did they discover the alcoholic ferment of yeast, but they had to exercise a wise selection in picking it out from others, and giving it special prominence. Place an old boot in a moist place, or expose common paste or a pot of jam to the air; it soon becomes coated with a blue-green mould, which is nothing else than the fructification of a little plant called *Penicillium glaucum*. Do not imagine that the mould has sprung spon-

taneously from boot, or paste, or jam; its germs, which are abundant in the air, have been sown, and have germinated, in as legal and legitimate a way as thistle-seeds wafted by the wind to a proper soil. Let the minute spores of *Penicillium* be sown in a fermentable liquid, which has been previously so boiled as to kill all other spores or seeds which it may contain; let pure air have free access to the mixture; the *Penicillium* will grow rapidly, striking long filaments into the liquid, and fructifying at its surface. Test the infusion at various stages of the plant's growth, you will never find in it a trace of alcohol. But forcibly submerge the little plant, push it down deep into the liquid, where the quantity of free oxygen that can reach it is insufficient for its needs, it immediately begins to act as a ferment, supplying itself with oxygen by the decomposition of the sugar, and producing alcohol as one of the results of the decomposition. Many other low microscopic plants act in a similar manner. In aërated liquids they flourish without any production of alcohol, but cut off from free oxygen they act as ferments, producing alcohol exactly as the real alcoholic leaven produces it, only less copiously. For the right apprehension of all these facts we are indebted to Pasteur.

In the cases hitherto considered, the fermentation is proved to be the invariable correlative of *life*, being produced by organisms foreign to the fermentable substance. But the substance itself may also have within it, to some extent, the motive power of fermentation. The yeast-plant, as we have learned, is an assemblage of living cells; but so at bottom, as shown by Schleiden and Schwann, are all living organisms. Cherries, apples, peaches, pears, plums, and grapes, for example, are composed of cells, each of which is a living unit. And here I have to direct your attention to a point of extreme interest. In 1821 the celebrated French chemist Bérard established the important fact that all ripening fruit, exposed to the free atmosphere, absorbed the oxygen of the atmosphere, and liberated an approximately equal volume of carbonic acid. He also found that when ripe fruits were placed in a confined atmosphere, the oxygen of the atmosphere was first absorbed, and an equal volume of carbonic acid given out. But the process did not end here. After

the oxygen had vanished, carbonic acid, in considerable quantities, continued to be exhaled by the fruits, which at the same time lost a portion of their sugar, becoming more acid to the taste, though the absolute quantity of acid was not augmented. This was an observation of capital importance, and Bérard had the sagacity to remark that the process might be regarded as a kind of fermentation.

Thus the living cells of fruits can absorb oxygen and breathe out carbonic acid, exactly like the living cells of the leaven of beer. Supposing the access of oxygen suddenly cut off, will the living fruit-cells as suddenly die, or will they continue to live as yeast lives, by extracting oxygen from the saccharine juices round them? This is a question of extreme theoretic significance. It was first answered affirmatively by the able and conclusive experiments of Lechartier and Bellamy, and the answer was subsequently confirmed and explained by the experiments and the reasoning of Pasteur. Bérard only showed the absorption of oxygen and the production of carbonic acid; Lechartier and Bellamy proved the production of alcohol, thus completing the evidence that it was a case of real fermentation, though the common alcoholic ferment was absent. So full was Pasteur of the idea that the cells of a fruit would continue to live at the expense of the sugar of the fruit, that once in his laboratory, while conversing on these subjects with M. Dumas, he exclaimed, "I will wager that if a grape be plunged into an atmosphere of carbonic acid, it will produce alcohol and carbonic acid by the continued life of its own cells—that they will act for a time like the cells of the true alcoholic leaven." He made the experiment, and found the result to be what he had foreseen. He then extended the inquiry. Placing under a bell-jar twenty-four plums, he filled the jar with carbonic acid gas; beside it he placed twenty-four similar plums uncovered. At the end of eight days he removed the plums from the jar, and compared them with the others. The difference was extraordinary. The uncovered fruits had become soft, watery, and very sweet; the others were firm and hard, their fleshy portions being not at all watery. They had, moreover, lost a considerable quantity of their sugar. They were afterwards bruised, and the juice was distilled.

It yielded six and a half grammes of alcohol, or one per cent. of the total weight of the plums. Neither in these plums, nor in the grapes first experimented on by Pasteur, could any trace of the ordinary alcoholic leaven be found. As previously proved by Lechartier and Bellamy, the fermentation was the work of the living cells of the fruit itself, after air had been denied to them. When, moreover, the cells were destroyed by bruising, no fermentation ensued. The fermentation was the correlative of a vital act, and it ceased when life was extinguished.

Lüdersdorf was the first to show by this method that yeast acted not, as Liebig had assumed, in virtue of its *organic*, but in virtue of its *organised* character. He destroyed the cells of yeast by rubbing them on a ground glass plate, and found that with the destruction of the organism, though its chemical constituents remained, the power to act as a ferment totally disappeared.

One word more in reference to Liebig may find a place here. To the philosophic chemist thoughtfully pondering these phenomena, familiar with the conception of molecular motion, and the changes produced by the interactions of purely chemical forces, nothing could be more natural than to see in the process of fermentation a simple illustration of molecular instability, the ferment propagating to surrounding molecular groups the overthrow of its own tottering combinations. Broadly considered, indeed, there is a certain amount of truth in this theory; but Liebig, who propounded it, missed the very kernel of the phenomena when he overlooked or contemned the part played in fermentation by microscopic life. He looked at the matter too little with the eye of the body, and too much with the spiritual eye. He practically neglected the microscope, and was unmoved by the knowledge which its revelations would have poured in upon his mind. His hypothesis, as I have said, was natural—nay, it was a striking illustration of Liebig's power to penetrate and unveil molecular actions; but it was an error, and as such has proved an *ignis fatuus* instead of a *pharos* to some of his followers.

I have said that our air is full of the germs of ferments

differing from the alcoholic leaven, and sometimes seriously interfering with the latter. They are the weeds of this microscopic garden which often overshadow and choke the flowers. Let us take an illustrative case. Expose boiled milk to the air. It will cool, and then turn sour, separating like blood into clot and serum. Place a drop of this sour milk under a powerful microscope and watch it closely. You see the minute butter-globules animated by that curious quivering motion called the Brownian motion.* But let not this attract your attention too much, for it is another motion that we have now to seek. Here and there you observe a greater disturbance than ordinary among the globules; keep your eye upon the place of tumult, and you will probably see emerging from it a long eel-like organism, tossing the globules aside and wriggling more or less rapidly across the field of the microscope. Familiar with one sample of this organism, which from its motions receives the name of vibrio, you soon detect numbers of them. It is these organisms, and other analogous though apparently motionless ones, which by decomposing the milk render it sour and putrid. They are the lactic and putrid ferments, as the yeast-plant is the alcoholic ferment of sugar. Keep them and their germs out of your milk, and it will continue sweet. But milk may become putrid without becoming sour. Examine such putrid milk microscopically, and you find it swarming with shorter organisms, sometimes associated with the vibrios, sometimes alone, and often manifesting a wonderful alacrity of motion. Keep these organisms and their germs out of your milk, and it will never putrefy. Expose a mutton-chop to the air and keep it moist; in summer weather it soon stinks. Place a drop of the juice of the fetid chop under a powerful microscope; it is seen swarming with organisms resembling those in the putrid milk. These organisms, which receive the common name of bacteria,† are the agents of all putrefaction. Keep them and their germs from your meat, and it will remain for ever sweet. Thus we begin to see that within the world of life to which we our-

* Which I am inclined to regard as an effect of surface tension.

† Doubtless organisms exhibiting grave specific differences are grouped together under this common name.

selves belong, there is another living world requiring the microscope for its discernment, but which, nevertheless, has the most important bearing on the welfare of the higher life-world.

And now let us reason together as regards the origin of these bacteria. A granular powder is placed in your hands, and you are asked to state what it is. You examine it, and have, or have not, reason to suspect that seeds of some kind are mixed up in it. But you prepare a bed in your garden, sow in it the powder, and soon after find a mixed crop of docks and thistles sprouting from your bed. Until this powder was sown neither docks nor thistles ever made their appearance in your garden. You repeat the experiment once, twice, ten times, fifty times. From fifty different beds after the sowing of the powder you obtain the same crop. What will be your response to the question proposed to you? "I am not in a condition," you would say, "to affirm that every grain of the powder is a dock-seed or a thistle-seed; but I am in a condition to affirm that both dock and thistle seeds form, at all events, part of the powder." Supposing a succession of such powders to be placed in your hands with grains becoming gradually smaller, until they dwindle to the size of impalpable dust particles; assuming that you treat them all in the same way, and that from every one of them in a few days you obtain a definite crop—it may be clover, it may be mustard, it may be mignonette, it may be a plant more minute than any of these, the smallness of the particles, or of the plants that spring from them, does not affect the validity of the conclusion. Without a shadow of misgiving you would conclude that the powder must have contained the seeds or germs of the life observed. There is not in the range of physical science an experiment more conclusive nor an inference safer than this one.

Supposing the powder to be light enough to float in the air, and that you are enabled to see it there just as plainly as you saw the heavier powder in the palm of your hand. If the dust sown by the air instead of by the hand produce a definite living crop, with the same logical rigour you would conclude that the germs of this crop must be mixed with the dust. To take an illustration: the spores of the little plant

Penicillium glaucum, to which I have already referred, are light enough to float in the air. A cut apple, a pear, a tomato, a slice of vegetable marrow, or, as already mentioned, an old moist boot, a dish of paste, or a pot of jam, constitutes a proper soil for the *Penicillium*. Now, if it could be proved that the dust of the air when sown in this soil produces this plant, while, wanting the dust, neither the air nor the soil, nor both together, can produce it, it would be obviously just as certain in this case that the floating dust contains the germs of *Penicillium* as that the powders sown in your garden contained the germs of the plants which sprung from them.

But how is the floating dust to be rendered visible? In this way. Build a little chamber and provide it with a door, windows, and window-shutters. Let an aperture be made in one of the shutters, through which a sunbeam can pass. Close the door and windows so that no light shall enter save through the hole in the shutter. The track of the sunbeam is at first perfectly plain and vivid in the air of the room. If all disturbance of the air of the chamber be avoided, the luminous track will become fainter and fainter, until at last it disappears absolutely, and no trace of the beam is to be seen. What rendered the beam visible at first? The floating dust of the air, which, thus illuminated and observed, is as palpable to sense as any dust or powder placed on the palm of the hand. In the still air the dust gradually sinks to the floor, or sticks to the walls and ceiling, until finally, by this self-cleansing process, the air is entirely freed from mechanically suspended matter.

Thus far, I think, we have made our footing sure. Let us proceed. Chop up a beefsteak and allow it to remain for two or three hours just covered with warm water; you thus extract the juice of the beef in a concentrated form. By properly boiling the liquid and filtering it you can obtain from it a perfectly transparent beef-tea. Expose a number of vessels containing this tea to the moteless air of your chamber; and expose a number of similar vessels containing precisely the same liquid to the dust-laden air. In three days every one of the latter stinks, and examined with the microscope every one of them is found swarming with

the bacteria of putrefaction. After three months, or three years, the beef-tea within the chamber is found in every case as sweet and clear, and as free from bacteria as it was at the moment when it was first put in. There is absolutely no difference between the air within and that without, save that the one is dustless and the other dust-laden. Clinch the experiment thus: Open the door of your chamber and allow the dust to enter it. In three days afterwards you have every vessel within the chamber swarming with bacteria, and in a state of active putrefaction. Here, also, the inference is quite as certain as in the case of the powder sown in your garden. Multiply your proofs by building fifty chambers instead of one, and by employing every imaginable infusion of wild animals and tame; of flesh, fish, fowl, and viscera; of vegetables of the most various kinds. If in all these cases you find the dust infallibly producing its crop of bacteria, while neither the dustless air nor the nutritive infusion, nor both together, are ever able to produce this crop, your conclusion is simply irresistible that the dust of the air contains the germs of the crop which has appeared in your infusions. I repeat there is no inference of experimental science more certain than this one. In the presence of such facts, to use the words of a paper lately published in the "Philosophical Transactions," it would be simply monstrous to affirm that these swarming crops of bacteria are spontaneously generated.

Is there, then, no experimental proof of spontaneous generation? I answer without hesitation, *none!* But to doubt the experimental proof of a fact, and to deny its possibility, are two different things, though some writers confuse matters by making them synonymous. In fact, this doctrine of spontaneous generation, in one form or another, falls in with the theoretic beliefs of some of the foremost workers of this age; but it is exactly these men who have the penetration to see, and the honesty to expose, the weakness of the evidence adduced in its support.

And here observe how these discoveries tally with the common practices of life. Heat kills the bacteria, cold numbs them. When my housekeeper has pheasants in

charge which she wishes to keep sweet, but which threaten to give way, she partially cooks the birds, kills the infant bacteria, and thus postpones the evil day. By boiling her milk she also extends its period of sweetness. Some weeks ago in the Alps I made a few experiments on the influence of cold upon ants. Though the sun was strong, patches of snow still maintained themselves on the mountain slopes. The ants were found in the warm grass and on the warm rocks adjacent. Transferred to the snow, the rapidity of their paralysis was surprising. In a few seconds a vigorous ant, after a few languid struggles, would wholly lose its power of locomotion, and lie practically dead upon the snow. Transferred to the warm rock, it would revive, to be again smitten with death-like numbness when retransferred to the snow. What is true of the ant is specially true of our bacteria. Their active life is suspended by cold, and with it their power of producing or continuing putrefaction. This is the whole philosophy of the preservation of meat by cold. The fishmonger, for example, when he surrounds his very assailable wares by lumps of ice, stays the process of putrefaction by reducing to numbness and inaction the organisms which produce it, and in the absence of which his fish would remain sweet and sound. It is the astonishing activity into which these bacteria are pushed by warmth that renders a single summer's day sometimes so disastrous to the great butchers of London and Glasgow. The bodies of guides lost in the crevasses of Alpine glaciers have come to the surface forty years after their interment, without the flesh showing any sign of putrefaction. But the most astonishing case of this kind is that of the hairy elephant of Siberia which was found encased in ice. It had been buried for ages, but when laid bare its flesh was sweet, and for some time afforded copious nutriment to the wild beasts which fed upon it.

Beer is assailable by all the organisms here referred to, some of which produce acetic, some lactic, and some butyric acid, while yeast is open to attack from the bacteria of putrefaction. In relation to the particular beverage the brewer wishes to produce, these foreign ferments have been properly called *ferments of disease*. The cells of the true leaven are globules, usually somewhat elongated. The other

organisms are more or less rod-like or eel-like in shape, some of them being beaded so as to resemble necklaces. Each of these organisms produces a fermentation and a flavour peculiar to itself. Keep them out of your beer, and it remains for ever unaltered. Never without them will your beer contract disease. But their germs are in the air, in the vessels employed in the brewery; even in the yeast used to impregnate the wort. Consciously or unconsciously, the art of the brewer is directed against them. His aim is to paralyse if he cannot annihilate them.

For beer, moreover, the question of temperature is one of supreme importance; indeed the recognised influence of temperature is causing on the continent of Europe a complete revolution in the manufacture of beer. When I was a student in Berlin, in 1851, there were certain places specially devoted to the sale of Bavarian beer, which was then making its way into public favour. This beer is prepared by what is called the process of *low fermentation;* the name being given partly because the yeast of the beer, instead of rising to the top and issuing through the bunghole, falls to the bottom of the cask; but partly, also, because it is produced at a low temperature. The other and older process, called *high fermentation,* is far more handy, expeditious, and cheap. In high fermentation eight days suffice for the production of the beer; in low fermentation, ten, fifteen, even twenty days are found necessary. Vast quantities of ice, moreover, are consumed in the process of low fermentation. In the single brewery of Dreher, of Vienna, a hundred million pounds of ice are consumed annually in cooling the wort and beer. Notwithstanding these obvious and weighty drawbacks, the low fermentation is rapidly displacing the high upon the Continent. Here are some statistics which show the number of breweries of both kinds existing in Bohemia in 1860, 1865, and 1870:

	1860.	1865.	1870.
High Fermentation . .	281	81	18
Low Fermentation . .	135	459	831

Thus in ten years the number of high-fermentation breweries fell from 281 to 18, while the number of low-fermentation breweries rose from 135 to 831. The sole

reason for this vast change—a change which involves a greater expenditure of time, labour, and money—is the additional command which it gives the brewer over the fortuitous ferments of disease. These ferments, which, it is to be remembered, are living organisms, have their activity suspended by temperatures below 10° C., and as long as they are reduced to torpor the beer remains untainted either by acidity or putrefaction. The beer of low fermentation is brewed in winter, and kept in cool cellars; the brewer being thus enabled to dispose of it at his leisure, instead of forcing its consumption to avoid the loss involved in its alteration if kept too long. Hops, it may be remarked, act to some extent as an antiseptic to beer. The essential oil of the hop is bactericidal: hence the strong impregnation with hop juice of all beer intended for exportation.

These low organisms, which one might be disposed to regard as the beginnings of life, were we not warned that the microscope, precious and perfect as it is, has no power to show us the real beginnings of life, are by no means purely useless or purely mischievous in the economy of nature. They are only noxious when out of their proper place. They exercise a useful and valuable function as the burners and consumers of dead matter, animal and vegetable, reducing such matter, with a rapidity otherwise unattainable, to innocent carbonic acid and water. Furthermore, they are not all alike, and it is only restricted classes of them that are really dangerous to man. One difference in their habits is worthy of special reference here. Air, or rather the oxygen of the air, which is absolutely necessary to the support of the bacteria of putrefaction, is absolutely deadly to the vibrios which provoke the butyric acid fermentation. This is most simply illustrated by the following beautiful observation of Pasteur. You know the way of looking at these small organisms through the microscope. A drop of the liquid containing them is placed upon glass, and on the drop is placed a circle of exceedingly thin glass; for, to magnify them sufficiently, it is necessary that the microscope should come very close to the organisms. Round the edge of the circular plate of glass the liquid is in contact with the air, and incessantly absorbs it, including the oxy-

gen. Here, if the drop be charged with bacteria, we have a zone of very lively ones. But through this living zone, greedy of oxygen and appropriating it, the vivifying gas cannot penetrate to the centre of the film. In the middle, therefore, the bacteria die, while their peripheral colleagues continue active. If a bubble of air chance to be enclosed in the film, round it the bacteria will pirouette and wabble until its oxygen has been absorbed, after which all their motions cease. Precisely the reverse of all this occurs with the vibrios of butyric acid. In their case it is the peripheral organisms that are first killed, the central ones remaining vigorous while ringed by a zone of dead. Pasteur, moreover, filled two vessels with a liquid containing these vibrios; through one vessel he led air, and killed its vibrios in half-an-hour; through the other he led carbonic acid, and after three hours found the vibrios fully active. It was while observing these differences of deportment fifteen years ago that the thought of life without air, and its bearing upon the theory of fermentation, flashed upon the mind of this admirable investigator.

And here I am tempted to inquire how it is that during the last five or six years so many of the cultivated English and American public, including members of the medical profession and contributors to some of our most intellectual journals, could be so turned aside as they have been from the pure well-spring of scientific truth to be found in the writings of Pasteur? The reason I take to be, that while against unsound logic a healthy mind can always defend itself, against unsound experiment, without discipline it is defenceless. To judge of the soundness of scientific data, and to reason from data assumed to be sound, are two totally different things. The one deals with the raw material of fact, the other with the logical textures woven from that material. Now the logical loom may go accurately through all its motions, while the woven fibres may be all rotten. It is this inability, through lack of education in experiment, to judge of the soundness of experimental work, which lies at the root of the defection from Pasteur.

I will cite an example of this mistake of judgment. Between the large-type articles and the reviews of the

Saturday Review essays on various subjects are interpolated. In the calm of holiday evenings, while reading these brief essays, I have been many a time impressed, not only with their sparkling cleverness, but with their deep-searching wisdom and their wealth of spiritual experience. In this central region of the *Review* the question of spontaneous generation has been taken up and discussed. The writer is not a whit behind his colleagues in literary brilliancy and logical force. But having no touchstone in his own experience to enable him to distinguish a good experiment from a bad one, he has, on a point of the gravest practical import, committed the influence of the powerful journal in which he writes to the support of error. It is only, I would repeat, by practice among facts that the intellect is prepared to judge of facts, and no mere logical acuteness or literary skill can atone for the want of this necessary education.

We now approach an aspect of this question which concerns us still more closely, and which will be best illustrated by an actual fact. A few years ago I was bathing in an Alpine stream, and returning to my clothes from the cascade which had been my shower-bath, I slipped upon a block of granite, the sharp crystals of which stamped themselves into my naked shin. The wound was an awkward one, but being in vigorous health at the time, I hoped for a speedy recovery. Dipping a clean pocket handkerchief into the stream, I wrapped it round the wound, limped home, and remained for four or five days quietly in bed. There was no pain, and at the end of this time I thought myself quite fit to quit my room. The wound, when uncovered, was found perfectly clean, uninflamed, and entirely free from matter. Placing over it a bit of goldbeater's skin, I walked about all day. Towards evening itching and heat were felt; a large accumulation of matter followed, and I was forced to go to bed again. The water-bandage was restored, but it was powerless to check the action now set up; arnica was applied, but it made matters worse. The inflammation increased alarmingly, until finally I was ignobly carried on men's shoulders down the mountain and transported to Geneva, where, thanks to the kindness of friends, I was

immediately placed in the best medical hands. On the morning after my arrival in Geneva, Dr Gautier discovered an abscess in my instep, at a distance of five inches from the wound. The two were connected by a channel, or *sinus*, as it is technically called, through which he was able to empty the abscess, without the application of the lance.

By what agency was that channel formed—what was it that thus tore asunder the sound tissue of my instep, and kept me for six weeks a prisoner in bed? In the very room where the water-dressing had been removed from my wound and the goldbeater's skin applied to it, I opened this year a number of tubes, containing perfectly clear and sweet infusions of fish, flesh, and vegetable. These hermetically sealed infusions had been exposed for weeks, both to the sun of the Alps and to the warmth of a kitchen, without showing the slightest turbidity or sign of life. But two days after they were opened the greater number of them swarmed with the bacteria of putrefaction, the germs of which had been contracted from the dust-laden air of the room. And had the matter from my abscess been examined, my memory of its appearance leads me to infer that it would have been found equally swarming with these bacteria—that it was their germs which got into my incautiously-opened wound, and that they were the subtle workers that burrowed down my shin, dug the abscess in my instep, and produced effects which might well have proved fatal to me.

We here come face to face with the labours of a man who has established for himself an imperishable reputation in relation to this subject, who combines the penetration of the true theorist with the skill and conscientiousness of the true experimenter, and whose practice is one continued demonstration of the theory that the putrefaction of wounds is to be averted by the destruction of the germs of bacteria. Not only from his own reports of his cases, but from the reports of eminent men who havo visited his hospital, and from the opinions expressed to me by Continental surgeons, do I gather that one of the greatest steps ever made in the art ot surgery was the introduction of tho antiseptic system ot treatment, practised, first in Glasgow, and now in Edinburgh, by Professor Lister.

The interest of this subject does not slacken as we proceed. We began with the cherry-cask and beer-vat; we end with the body of man. There are persons born with the power of interpreting natural facts, as there are others smitten with everlasting incompetence in regard to such interpretation. To the former class in an eminent degree belonged the celebrated philosopher Robert Boyle, whose words in relation to this subject have in them the forecast of prophecy. "And let me add," writes Boyle in his "Essay on the Pathological Part of Physik," "that he that thoroughly understands the nature of ferments and fermentations shall probably be much better able than he that ignores them, to give a fair account of divers phenomena of several diseases (as well fevers as others) which will perhaps be never properly understood without an insight into the doctrine of fermentations."

Two hundred years have passed since these pregnant words were written, and it is only in this our day that men are beginning to fully realise their truth. In the domain of surgery the justice of Boyle's surmise has been most strictly demonstrated. Demonstration is indeed the only word which fitly characterises the evidence brought forward by Professor Lister. You will grasp in a moment his leading idea. Take the extracted juice of beef or mutton, so prepared as to be perfectly transparent, and entirely free from the living germs of bacteria. Into the clear liquid let fall the tiniest drop of an infusion charged with the bacteria of putrefaction. Twenty-four hours subsequently the clear extract will be found muddy throughout, the turbidity being due to swarms of bacteria generated by the drop with which the infusion was inoculated. At the same time the infusion will have passed from a state of sweetness to a state of putridity. Let a drop similar to that which has produced this effect fall into an open wound: the juices of the living body nourish the bacteria as the beef or mutton juice nourished them, and you have putrefaction produced within the system. The air, as I have said, is laden with floating matter which, when it falls upon the wound, acts substantially like the drop. Professor Lister's aim is to destroy the life of that floating matter—to kill such germs as it may

contain. Had he, for example, dressed my wound, instead of opening it incautiously in the midst of air laden with the germs of bacteria, and instead of applying to it goldbeater's skin, which probably carried these germs upon its surface, he would have showered upon the wound, during the time of dressing, the spray of some liquid capable of killing the germs. The liquid usually employed for this purpose is dilute carbolic acid, which, in his skilled hands, has become a specific against putrefaction and all its deadly consequences.

We now pass the bounds of surgery proper, and enter the domain of epidemic disease, including those fevers so sagaciously referred to by Boyle. The most striking analogy between a *contagium* and a ferment is to be found in the power of indefinite self-multiplication possessed and exercised by both. You know the exquisitely truthful figures regarding leaven employed in the New Testament. A particle hid in three measures of meal leavens it all. A little leaven leaveneth the whole lump. In a similar manner a particle of *contagium* spreads through the human body and may be so multiplied as to strike down whole populations. Consider the effect produced upon the system by a microscopic quantity of the virus of smallpox. That virus is to all intents and purposes a seed. It is sown as yeast is sown, it grows and multiplies as yeast grows and multiplies, and it always reproduces itself. To Pasteur we are indebted for a series of masterly researches, wherein he exposes the looseness and general baselessness of prevalent notions regarding the transmutation of one ferment into another. He guards himself against saying it is impossible. The true investigator is sparing in the use of this word, though the use of it is unsparingly ascribed to him; but, as a matter of fact, Pasteur has never been able to effect the alleged transmutation, while he has been always able to point out the open doorways through which the affirmers of such transmutations had allowed error to march in upon them.*

* Those who wish for an illustration of the care necessary in these researches, and of the carelessness with which they have in some cases been conducted, will do well to consult the Rev. W. H. Dallinger's excellent "Notes on Heterogenesis" in the October number of the *Popular Science Review*.

The great source of error here has been already alluded to in this discourse. The observers worked in an atmosphere charged with the germs of different organisms; the mere accident of first possession rendering now one organism, now another, triumphant. In different stages, moreover, of its fermentative or putrefactive changes, the same infusion may so alter as to be successively taken possession of by different organisms. Such cases have been adduced to show that the earlier organisms must have been transformed into the later ones, whereas they are simply cases in which different germs, because of changes in the infusion, render themselves valid at different times.

By teaching us how to cultivate each ferment in its purity,—in other words, by teaching us how to rear the individual organism apart from all others—Pasteur has enabled us to avoid all these errors. And where this isolation of a particular organism has been duly effected it grows and multiplies indefinitely, but no change of it into another organism is ever observed. In Pasteur's researches the Bacterium remained a Bacterium, the Vibrio a Vibrio, the Penicillium a Penicillium, and the Torula a Torula. Sow any of these in a state of purity in an appropriate liquid; you get it, and it alone, in the subsequent crop. In like manner, sow smallpox in the human body, your crop is smallpox. Sow there scarlatina, and your crop is scarlatina. Sow typhoid virus, your crop is typhoid—cholera, your crop is cholera. The disease bears as constant a relation to its contagium as the microscopic organisms just enumerated do to their germs, or indeed as a thistle does to its seed. No wonder, then, with analogies so obvious and so striking, that the conviction is spreading and growing daily in strength that reproductive parasitic life is at the root of epidemic disease—that living ferments finding lodgment in the body increase there and multiply, directly ruining the tissue on which they subsist, or destroying life indirectly by the generation of poisonous compounds within the body. This conclusion, which comes to us with a presumption almost amounting to demonstration, is clinched by the fact that virulently infective diseases have been discovered with which living organisms are as closely and as indissolubly

associated as the growth of Torula is with the fermentation of beer.

And here, if you will permit me, I would utter a word of warning to well-meaning people. We have now reached a phase of this question when it is of the very last importance that light should once for all be thrown upon the manner in which contagious and infectious diseases take root and spread. To this end the action of various ferments upon the organs and tissues of the living body must be studied; the habitat of each special organism concerned in the production of each specific disease must be determined, and the mode by which its germs are spread abroad as sources of further infection. It is only by such rigidly accurate inquiries that we can obtain final and complete mastery over these destroyers. Hence, while abhorring cruelty of all kinds, while shrinking sympathetically from all animal suffering—suffering which my own pursuits never call upon me to inflict, an unbiassed survey of the field of research now opening out before the physiologist causes me to conclude, that no greater calamity could befall the human race than the stoppage of experimental inquiry in this direction. A lady whose philanthropy has rendered her illustrious said to me some time ago, that science was becoming immoral; that the researches of the past, unlike those of the present, were carried on without cruelty. I replied to her that the science of Kepler and Newton, to which she referred, dealt with the laws and phenomena of inorganic nature; but that one great advance made by modern science was in the direction of biology, or the science of life; and that in this new direction scientific inquiry, though at the outset pursued at the cost of some temporary suffering, would in the end prove a thousand times more beneficent than it had ever hitherto been. I said this because I saw that the very researches which the lady deprecated were leading us to such a knowledge of epidemic diseases, as will enable us finally to sweep these scourges of the human race from the face of this fair earth.

This is a point of such special importance that I should like to bring it home to your intelligence by a single trustworthy illustration. In 1850 two distinguished French

observers, MM. Davainne and Rayer, noticed in the blood of animals which had died of the virulent disease called *splenic fever*, small microscopic organisms resembling transparent rods, but neither of them at that time attached any significance to the observation. In 1861 Pasteur published a memoir on the fermentation of butyric acid, wherein he described the organism which provoked it; and after reading this memoir it occurred to Davainne that splenic fever might be a case of fermentation set up within the animal body, by the organisms which had been observed by him and Rayer. This idea has been placed beyond all doubt by subsequent research.

Some years in advance of the labours undertaken by Davainne, observations of the highest importance had been made on splenic fever by Pollender and Brauell. Two years ago, Dr Burdon Sanderson gave us a very clear account of what was known up to that time of this disorder. With regard to the permanence of the contagium, it had been proved to hang for years about localities where it had once prevailed; and this seemed to show that the rod-like organisms could not constitute the contagium, because their infective power was found to vanish in a few weeks. But other facts established an intimate connection between the organisms and the disease, so that a review of all the facts caused Dr Sanderson to conclude that the contagium existed in two distinct forms: the one "fugitive" and visible as transparent rods; the other permanent but "latent," and not yet brought within the grasp of the microscope.

At the time that Dr Sanderson was writing this report, a young German physician, named Koch, occupied with the duties of his profession in an obscure country district, was already at work, applying, during his spare time, various original and ingenious devices to the investigation of splenic fever. He studied the habits of the rod-like organisms, and found the aqueous humour of an ox's eye to be particularly suitable for their nutrition. With a drop of the aqueous humour he mixed the tiniest speck of a liquid containing the rods, placed the drop under his microscope, warmed it suitably, and observed the subsequent action. During the first two hours hardly any change was noticeable; but at the

end of this time the rods began to lengthen, and the action was so rapid that at the end of three or four hours they attained from ten to twenty times their original length. At the end of a few additional hours they had formed filaments in many cases a hundred times the length of the original rods. The same filament, in fact, was frequently observed to stretch through several fields of the microscope. Sometimes they lay in straight lines parallel to each other, in other cases they were bent, twisted, and coiled into the most graceful figures; while sometimes they formed knots of such bewildering complexity that it was impossible for the eye to trace the individual filaments through the confusion.

Had the observation ended here an interesting scientific fact would have been added to our previous store, but the addition would have been of little practical value. Koch, however, continued to watch the filaments, and after a time noticed little dots appearing within them. These dots became more and more distinct, until finally the whole length of the organism was studded with minute ovoid bodies, which lay within the outer integument like peas within their shell. By-and-by the integument fell to pieces, the place of the organism being taken by a long row of seeds or spores. These observations, which were confirmed in all respects by the celebrated naturalist, Cohn of Breslau, are of the highest importance. They clear up the existing perplexity regarding the latent and visible contagia of splenic fever; for in the most conclusive manner, Koch proved the spores, as distinguished from the rods, to constitute the contagium of the fever in its most deadly and persistent form.

How did he reach this important result? Mark the answer. There was but one way open to him to test the activity of the contagium, and that was the inoculation with it of living animals. He operated upon guinea-pigs and rabbits, but the vast majority of his experiments were made upon mice. Inoculating them with the fresh blood of an animal suffering from splenic fever, they invariably died of the same disease within twenty or thirty hours after inoculation. He then sought to determine how the contagium maintained its vitality. Drying the infectious blood containing the rod-like organisms, in which, however, the spores

were not developed, he found the contagium to be that which Dr Sanderson calls "fugitive." It maintained its power of infection for five weeks at the furthest. He then dried blood containing the fully-developed spores, and exposed the substance to a variety of conditions. He permitted the dried blood to assume the form of dust; wetted this dust, allowed it to dry again, permitted it to remain for an indefinite time in the midst of putrefying matter, and subjected it to various other tests. After keeping the spore-charged blood which had been treated in this fashion for four years, he inoculated a number of mice with it, and found its action as fatal as that of blood fresh from the veins of an animal suffering from splenic fever. There was no single escape from death after inoculation by this deadly contagium. Uncounted millions of these spores are developed in the body of every animal which has died of splenic fever, and every spore of these millions is competent to produce the disease. The name of this formidable parasite is *Bacillus anthracis*.*

Now the very first step towards the extirpation of these contagia is the knowledge of their nature; and the knowledge brought to us by Dr Koch will render as certain the stamping out of splenic fever as the stoppage of the plague of pébrine by the researches of Pasteur. One small item of statistics will show what this implies. In the single district of Novgorod in Russia, between the years 1867 and 1870, over fifty-six thousand cases of death by splenic fever, among horses, cows, and sheep, were recorded. But its ravages did not confine themselves to the animal world, for during the time, and in the district referred to, five hundred and twenty-eight human beings perished in the agonies of the same disease.

* To produce its characteristic effects the contagium of splenic fever must enter the blood. The virulently infective spleen of a diseased animal may be eaten with impunity by mice. On the other hand, the disease refuses to be communicated by inoculation to dogs, partridges, or sparrows. In their blood *Bacillus anthracis* ceases to act as a ferment. Pasteur announced more than six years ago the propagation of the vitrios of the silkworm disease called *flacherie*, both by scission and by spores. He also made some remarkable experiments on the permanence of the contagium in the form of spores. See "Etudes sur la Maladie des Vers à Soie," pp. 168 and 256.

A description of the fever will help you to come to a right decision on the point which I wish to submit to your consideration. "An animal," says Dr Burdon Sanderson, "which perhaps for the previous day has declined food and shown signs of general disturbance, begins to shudder and to have twitches of the muscles of the back, and soon after becomes weak and listless. In the meantime the respiration becomes frequent and often difficult, and the temperature rises to three or four degrees above the normal; but soon convulsions, affecting chiefly the muscles of the back and loins, usher in the final collapse, of which the progress is marked by complete loss of power of moving the trunk or extremities, diminution of temperature, mucous and sanguinolent alvine evacuations, and similar discharges from the mouth and nose." In a single district of Russia, as above remarked, fifty-six thousand horses, cows, and sheep, and five hundred and twenty-eight men and women, perished in this way during a period of two or three years. What the annual fatality is throughout Europe I have no means of knowing. Doubtless it must be very great. The question, then, which I wish to submit to your judgment is this: Is the knowledge which reveals to us the nature, and which assures the extirpation, of a disorder so virulent and so vile, worth the price paid for it? It is exceedingly important that assemblies like the present should see clearly the issues at stake in such questions as this, and that the properly-informed common sense of the community should temper, if not restrain, the rashness of those who, meaning to be tender, would virtually enact the most hideous cruelty by the imposition of short-sighted restrictions upon physiological investigation. It is a modern instance of zeal for God, but not according to knowledge, the excesses of which zeal an instructed public opinion must correct.

And now let us cast a backward glance on the field we have traversed, and try to extract from our labours such further profit as they can yield. For more than two thousand years the attraction of light bodies by amber was the sum of human knowledge regarding electricity, and for more than two thousand years fermentation was effected without

any knowledge of its cause. In science one discovery grows out of another, and cannot appear without its proper antecedent. Thus, before fermentation could be understood, the microscope had to be invented and brought to a considerable degree of perfection. Note the growth of knowledge. Leeuwenhoek, in 1680, found yeast to be a mass of floating globules, but he had no notion that the globules were alive. This was proved in 1835 by Cagniard de la Tour and Schwann. Then came the question as to the origin of such microscopic organisms, and in this connection the memoir of Pasteur, published in the "Annales de Chimie" for 1862, is epoch-making, proving as it did to all competent minds spontaneous generation to be thus far a chimera. On that investigation all Pasteur's subsequent labours were based. Ravages had over and over again occurred among French wines. There was no guarantee that they would not become acid or bitter, particularly when exported. The commerce in wines was thus restricted, and disastrous losses were often inflicted on the wine-grower. Every one of these diseases was traced to the life of an organism. Pasteur ascertained the temperature which killed these ferments of disease, proving it to be so low as to be perfectly harmless to the wine. By the simple expedient of heating the wine to a temperature of fifty degrees centigrade, he rendered it inalterable, and thus saved his country the loss of millions. He then went on to vinegar—*vin aigre*, acid wine—which he proved to be produced by a fermentation set up by a little fungus called *Mycoderma aceti*. *Torula*, in fact, converts the grape juice into alcohol, and *Mycoderma aceti* converts the alcohol into vinegar. Here also frequent failures occurred and severe losses were sustained. Through the operation of unknown causes, the vinegar often became unfit for use, sometimes indeed falling into utter putridity. It had been long known that mere exposure to the air was sufficient to destroy it. Pasteur studied all these changes, traced them to their living causes, and showed that the permanent health of the vinegar was ensured by the destruction of this life. He passed from the diseases of vinegar to the study of a malady which a dozen years ago had all but ruined the silk husbandry of France. This plague, which received the name of *pébrine*, was the

product of a parasite which first took possession of the intestinal canal of the silkworm, spread throughout its body, and filled the sack which ought to contain the viscid matter of the silk. Thus smitten, the worm would go automatically through the process of spinning when it had nothing to spin. Pasteur followed this parasitic destroyer from year to year, and, led by his singular power of combining facts with the logic of facts, discovered eventually the precise phase in the development of the insect when the disease which assailed it could with certainty be stamped out. Pasteur's devotion to this inquiry cost him dear. He restored to France her silk husbandry, rescued thousands of her population from ruin, set the looms of Italy also to work, but emerged from his labours with one of his sides permanently paralysed. His last investigation is embodied in a work entitled "Studies on Beer," in which he describes a method of rendering beer permanently unchangeable. That method is not so simple as those found effectual with wine and vinegar, but the principles which it involves are sure to receive extensive application at some future day. Taking into account all these labours of Pasteur, it is no exaggeration to state that the money value of his work would go far to cover the indemnity which France had to pay to Germany.

There are other reflections connected with this subject which, even were I to pass them over without remark, would sooner or later occur to every thoughtful mind in this assembly. I have spoken of the floating dust of the air, of the means of rendering it visible, and of the perfect immunity from putrefaction which accompanies the contact of germless matter and moteless air. Consider the woes which these wafted particles, during historic and pre-historic ages, have inflicted on mankind; consider the loss of life in hospitals from putrefying wounds; consider the loss of life in places where there are plenty of wounds but no hospitals, and in the ages before hospitals were anywhere founded; consider the slaughter which has hitherto followed that of the battle-field, when those bacterial destroyers are let loose, often producing a mortality far greater than that of the battle itself; add to this the other conception that in times of epidemic disease the self-same floating matter has fre-

quently, if not always, mingled with it the special germs which produce the epidemic, being thus enabled to sow pestilence and death over nations and continents—consider all this, and you will come with me to the conclusion that all the havoc of war, ten times multiplied, would be evanescent if compared with the ravages due to atmospheric dust.

This preventible destruction is going on to-day, and it has been permitted to go on for ages, without a whisper of information regarding its cause being vouchsafed to the suffering sentient world. We have been scourged by invisible thongs, attacked from impenetrable ambuscades, and it is only to-day that the light of science is being let in upon the murderous dominion of our foes. Men of Glasgow, facts like these excite in me the thought that the rule and governance of the universe are different from what we in our youth supposed them to be—that the inscrutable Power, at once terrible and beneficent, in whom we live and move and have our being and our end, is to be propitiated by means different from those usually resorted to. The first requisite towards such propitiation is *knowledge;* the second is *action,* shaped and illuminated by that knowledge. Of knowledge we already see the dawn, which will open out by-and-by to perfect day, while the action which is to follow has its unfailing source and stimulus in the moral and emotional nature of man—in his desire for personal well-being, in his sense of duty, in his compassionate sympathy with the sufferings of his fellow-men. "How often," says Dr William Budd in his celebrated work on Typhoid Fever,—"how often have I seen in past days, in the single narrow chamber of the day-labourer's cottage, the father in the coffin, the mother in the sick-bed in muttering delirium, and nothing to relieve the desolation of the children but the devotion of some poor neighbour, who in too many cases paid the penalty of her kindness in becoming herself the victim of the same disorder." From the vantage-ground already won I look forward with confident hope to the triumph of medical art over scenes of misery like that here described. The cause of the calamity being once clearly revealed, not only to the physician, but to the public, whose intelligent co-operation

is absolutely essential to success, the final victory of humanity is only a question of time. We have already a foretaste of that victory in the triumphs of surgery as practised at your doors.

And here, ladies and gentlemen, my words ought to cease. I have endeavoured to unfold in your presence discoveries and doctrines which have a special bearing on the life of great cities such as this, and which have a still wider bearing on the welfare of the human race. I regard it as a high privilege to have had the opportunity of meeting you here. I thank you for the courtesy you have extended to me. I wish prosperity to your association, long life to its president, and to each and all of you I bid a friendly farewell.

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